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PAPER FOR THE FIFTH ANNUAL AIAA/BMDO TECHNOLOGY READINESS CONFERENCE AND EXHIBIT

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Integration of the PAC-3 Missile Segment into the Patriot Air Defense System

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Abstract

The Patriot Air Defense System has been developed as a modular system with a high level of integrated software-driven functionality providing a broad range of inherent flexibility. The system has evolved from its initial, basic design which provided defense against the air breathing threat in complex countermeasure environments with a single Patriot missile type to the Patriot Advanced Capability "2" (PAC-2) which provides defense against a combination of the air breathing and tactical ballistic missile threats utilizing four missile types. The Patriot Air Defense System continues to evolve to the Patriot Advanced Capability "3" (PAC-3) configuration which incorporates radar and communication upgrades as well as the Lockheed Martin Vought Systems (LMVS) PAC-3 missile, a fifth missile type. As part of this capability, scheduled to be fielded in 1999, the Patriot Project Office (PPO) and the Ballistic Missile Defense Organization (BMDO) have contracted with Raytheon for the integration of the PAC-3 Missile Segment* into the Patriot Air Defense System. The goal of this program is to achieve a balanced design that provides a fielded capability which maximizes the kill potential of the PAC-3 missile while maintaining overall performance of the Patriot System. The modular hardware design and flexible software architecture of the Patriot Air Defense System supports a system design which meets this goal.

Introduction to Patriot

The PAC-3 development plan is a phased plan consisting of three incremental configurations that build on each other to achieve the full PAC-3 capability. To understand this development, the Patriot Air Defense System without any of the PAC-3 modifications will first be described.

The Patriot Air Defense System consists of up to six Patriot Fire units which operate in a battalion configuration under the Information Coordination Central (ICC). The ICC is interoperable with both Patriot and Hawk Fire Units. A Patriot Fire Unit consists of an Engagement Control Station (ECS), a Patriot Radar, up to sixteen launchers equipped with four missiles and canisters each, an Electric Power Plant (EPP) and an Antenna Mast Group (AMG). (See Figure 1) A Patriot Battalion adds the ICC and Communication Relay Groups (CRGs) to provide a higher echelon of command and control over the individual fire units.

The ECS is the only manned element at the fire unit level and contains a Weapons Control Computer (WCC), displays and controls for two operators and a Data Link terminal (DLT) which supports communications with the launchers either over VHF radio or fiber optic links. Additionally, UHF radios are provided for intra-battalion communication of voice and data and a Routing Logic Radio Interface Unit (RLRIU) is provided to route all communications and interface with the WCC.

The Patriot radar is a phased array which operates at C-Band and offers many features which support its ECM immunity such as pulse to pulse frequency diversity, side lobe blanking, side lobe cancellation and low antenna sidelobes. The radar simultaneously detects and tracks targets, provides the missile uplink and receives the missile downlink. It also provides the Target via Missile (TVM) illumination waveform which is received by the missile and the radar providing guidance data.

The Patriot launcher is trailer mounted and can be located up to twelve kilometers from the radar. The Launcher can hold up to four Patriot missiles mounted on a trainable bed. Three missile types may be used interchangeably on any launcher and are selected based on required capability on an engagement by engagement basis by the WCC. "Standard" missiles are preferred for use against Air Breathing Targets, "Stand Off Jammer Counter (SOJC)" missiles are preferred for use against dense formations of stand off jammers and "Patriot Advanced

* The PAC-3 Missile Segment, developed by Lockheed Martin Vought Systems (LMVS), is defined as the PAC-3 Missile Four Pack, the Fire Solution Computer (FSC) and the Enhanced Launcher Electronics Systems (ELES).

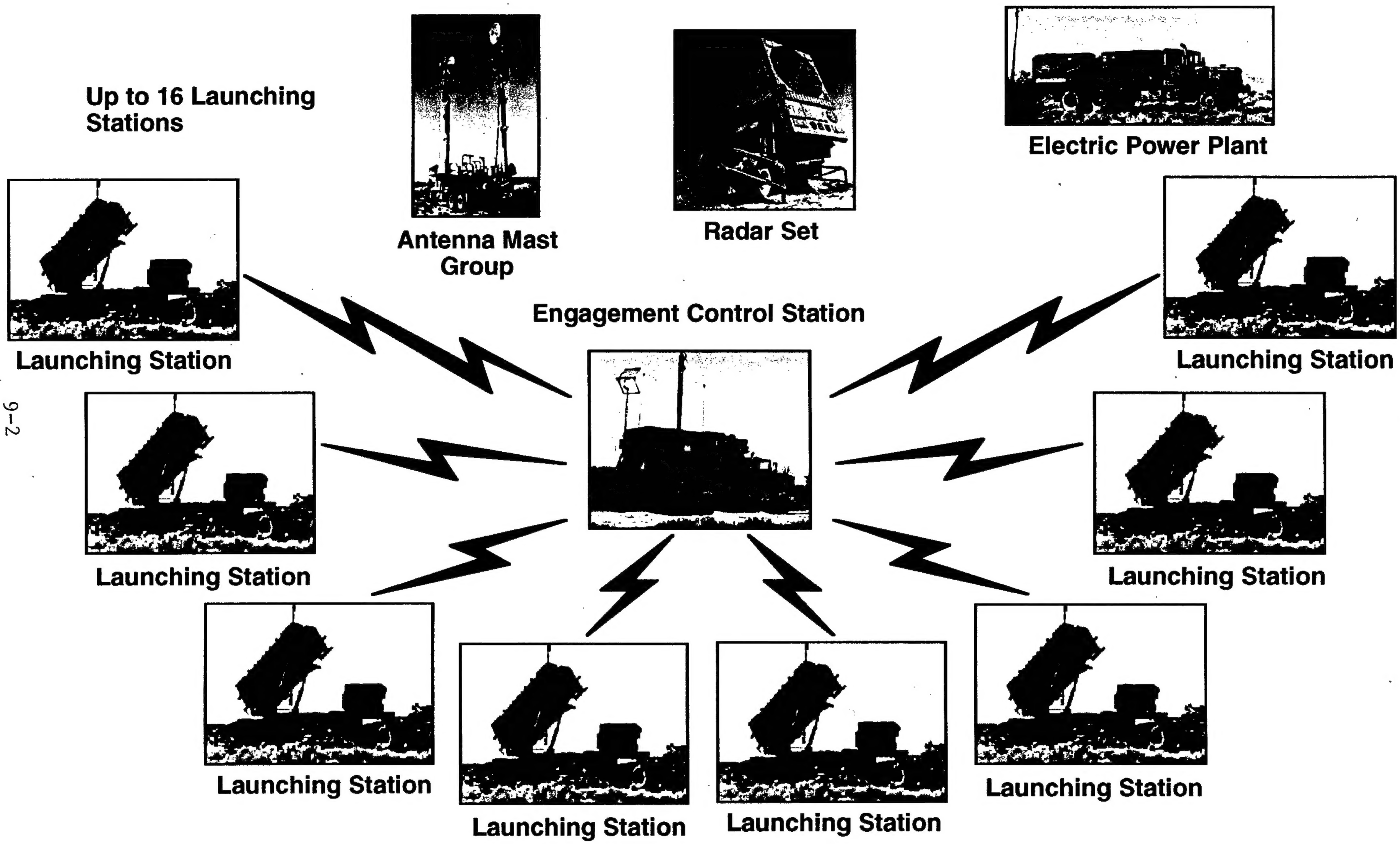

Figure 1. Patriot Fire Unit

Capability 2 (PAC-2)" missiles are preferred for use against Tactical Ballistic Missiles. A fourth missile type called the "Guidance Enhanced Missile (GEM)" which improves performance against TBMs may also be utilized on the launcher. The GEM missile is part of the phased PAC-3 development program.

The evolution from PAC-2 to PAC-3 consists of time phased incremental upgrades with the Quick Response program being the bridge between PAC-2 and the three PAC-3 configurations. The Quick Response program grew out of Desert Storm. This program implemented a low noise receiver in the Patriot radar lowering its noise figure by approximately 6.5 dB, a modification to the beam steering processor which lowered the antenna sidelobes by approximately 5 dB, a radar shroud to eliminate interference from entering the radar backlobes, automatic emplacement utilizing the Global Positioning System and a North Finding system and remote launch which allows launchers to be located up to 12 kilometers from the radar.

The first PAC-3 configuration (Configuration 1) incorporates the GEM missile which has a low noise receiver and enhanced fuze processor to improve performance against the TBM threat. The radar is upgraded with the Pulse Doppler Processor which improves performance of the pulse doppler waveform and reduces its dwell time thus improving radar performance. The ECS is upgraded with the Enhanced Weapon Control Computer (EWCC), Optical Disk (OD) and an embedded data recorder (EDR). The EWCC improves throughput by a factor of four and memory by a factor of eight. The OD improves reload time and reduces the time to load the maintenance software. The EDR allows for collection of tactical data in the field so that any system performance issues that may arise can be analyzed and solutions developed. Configuration 1 is currently being fielded.

The second PAC-3 configuration (Configuration 2) incorporates communication enhancements at the ICC which allow for direct communication over TADIL-A and TADIL-J links by the replacement of the RLRIU with an upgraded version (RLRIU-U). Additionally, the full capability of the radar pulse doppler processor is achieved through software modifications to the tactical software, in this case Post Deployment Build 4 (PDB-4). Several other modifications in PDB-4 software include enhanced survivability with the incorporation of Counter ARM features. Configuration 2 has recently completed operational test and will be fielded this calendar year.

The third PAC-3 configuration (Configuration 3) delivers the full PAC-3 capability. The radar transmitter is upgraded to double its duty cycle increasing its average transmitted power which increases detection range and improves multifunction performance. A new exciter is added to the radar to improve reliability and increase subclutter visibility. A wide band capability (transmit and receive) is also added to the radar to improve reliability and increase subclutter visibility. The wide band capability supports high range resolution measurements which improve the classification and discrimination of TBM targets in the presence of debris and pen-aides (warhead discrimination) as well as the classification of the air breathing threats and cruise missiles. The ECS, ICC and CRG are upgraded to extend the Remote Launch Phase-I capability so that launchers may be located in excess of 30 kilometers from the radar. This modification dramatically expands the TBM defended area.

As part of Configuration 3, the fifth missile type, the PAC-3 missile, is added to the Patriot repertoire which expands defended area against longer range TBMs, increases missile lethality against weapons of mass destruction via Hit-to-Kill technology and increases system firepower. To support the PAC-3 missile and improve launcher reliability and maintainability, several launcher systems are upgraded.

Demonstration/Validation Program

The integration activity began in 1991 when the ERINT Project Office (EPO) and the Patriot Project Office (PPO) began to explore the possibility of integrating the ERINT interceptor into Patriot. A cooperative activity involving the PPO, EPO, Raytheon and LTV (which became Loral Vought Systems and then LMVS) resulted in a Demonstration/Validation (Dem/Val) program to develop a concept, define interfaces and build and demonstrate hardware and software.

The Dem/Val integration development activity took place between November 1991 and September 1994 and formed the basis for the current design. In Dem/Val, the functional allocations emphasized the separation of the unique PAC-3 missile support functions from those supporting the overall Patriot system performance. As a goal, the PAC-3 missile support functions were isolated to the LMVS hardware and software. Interfaces between these functions were documented in Interface Control Specifications and the resulting hardware and software requirements to support these interfaces were defined. The joint Raytheon/LMVS program built prototype hardware and software and demonstrated the integration concept. Three phases of software integration testing were completed, including a final phase at White Sands Missile Range (WSMR) using government test assets (Radar, Launcher, and ECS). During software integration testing, numerous PAC-3 missile engagements were simulated against a wide range of targets including TBMs, ABTs, and ARMs to validate the integration concept and interface compatibility. While battle management software functionality was deferred until the Engineering and Manufacturing Development (EMD) program, the hardware and software interfaces were designed to be robust and were tested in anticipation of this additional functionality. In addition, effort was initiated to update Patriot training, provisioning, documentation, and logistics products.

Integration of PAC-3 Missile Segment Into a Fire Unit

Several design goals were developed to minimize life cycle costs and simplify implementation in support of the overall integration goals. First, the integration concept

should require minimal changes to the existing fielded Patriot system hardware and software. Second, all changes to add PAC-3 missile launch capability should be integrated into the existing Patriot training, provisioning, documentation, and logistics support functions. Third, there should be minimum duplication of function between Patriot software residing in existing computers and PAC-3 missile-unique software. Finally, the interfaces between the existing system elements and PAC-3 unique elements should be straightforward and easily definable in an Interface Control Specification.

Figure 2 illustrates the integration of the PAC-3 Missile Segment into a Patriot Fire Unit. All current and planned Patriot capabilities as well as the PAC-3 missile are supported. Each fire unit is planned to be fielded with PAC-3 missiles and a mixture of pre-PAC-3 missiles (Guidance Enhanced Missiles (GEM), PAC-2, SOJC, and Standard Patriot Missiles), providing maximum utilization of the existing inventory of Patriot missiles while still providing the capability of the PAC-3 missile.

The Fire Solution Computer (FSC) provides all PAC-3 missile-peculiar processing in the Engagement Control Station (ECS) and acts as a peripheral of the existing Patriot Enhanced Weapon Control Computer (EWCC) (Figure 3).

Selected track data from the Patriot Radar Set is sent from the EWCC to the FSC. The FSC generates an engagement solution if the PAC-3 missile can engage the target. The EWCC can then schedule and select a PAC-3 missile launch. The FSC continues to process the engaged track data after launch and determines when new data is to be passed to the missile; this is handled via an uplink request to the Patriot EWCC. The PAC-3 missile prelaunch data is generated by the FSC and sent to the EWCC. In the context of engagement operations, this architecture essentially allows the PAC-3 missile to be viewed as a new missile type added to the Patriot missile types already deployed and allows the EWCC to perform the integrated battle management function. In addition, this minimizes the amount of EWCC software which needs to be redesigned.

EWCC software modifications include development of new software functions to manage and service the new interface created for the FSC. Expansion of current Patriot software functions is also necessary to support the capability provided by the PAC-3 missile. First, modifications to the surveillance software are required to pass target track data to the FSC. Modifications to the engagement decision and weapons assignment logic are necessary to allow the PAC-3 missile and PAC-3 missile-capable launchers to be selected. It is necessary to modify the launcher communication software to format and communicate PAC-3 launch commands. Status monitor software must be modified to monitor and control PAC-3-capable launchers. Finally, modifications to the radar scheduling algorithms are required to process uplink requests from the FSC and to then receive resulting downlinks. It is expected that these functions will require less than a 14 percent change to the EWCC software.

<u>Launcher Communications</u>

The communications with the PAC-3 capable launchers is designed to be consistent with the message structure and communication protocols of the existing Patriot launcher communication system. New message data content, in the form of newly defined Launcher Actions Messages (LAM) and Launcher Response Messages (LRM), are defined to pass the PAC-3 missile peculiar data to the launcher. This design has several system advantages. It allows a single launcher communication net to support a mixture of the current launchers and the newer PAC-3 configured launchers; this is important because the Army requires the capability to deploy PAC-3 Fire Units with both types of launchers. This design provides logistic support advantages in that the set up, the operation, and maintenance of the net is not changed and is the same for all launchers in the net. This approach also has the advantage of capturing the PAC-3 launch capability within a strong, consistent design baseline and allows the PAC-3 launch capability to be included in other, concurrent, Patriot upgrade activity.

There are two concurrent activities that relate to the PAC-3 missile launch capability:

- <u>Increased message rate</u>: This activity, being performed under the PAC-3 missile integration contract, allows two independent launcher messages to be packed within the current message frame; at the launcher, the messages are separated and displaced by one half of the current message frame before being passed on to the launcher electronics. The effect of this is the doubling of the message data rate at the launcher electronics. While this provides overall launcher communication data rate improvements, full exploitation of the second data message requires the electronics of the PAC-3 capable launcher.
- <u>Remote launch Phase 3</u>: This separate PAC-3 system upgrade enhances Patriot's launch capability by allowing launchers to be grouped and placed at much greater distances from the Patriot battery. These remote groups operate within their own launcher communication net; communication with the remote group is via the Patriot battalion UHF communication net mentioned previously. Multiple remote groups can be defined within the Battalion, each with its own launcher communication net. Further, a "reconstitution" capability will allow a Fire Unit to take control of the launchers of another Fire Unit that has lost its radar function.

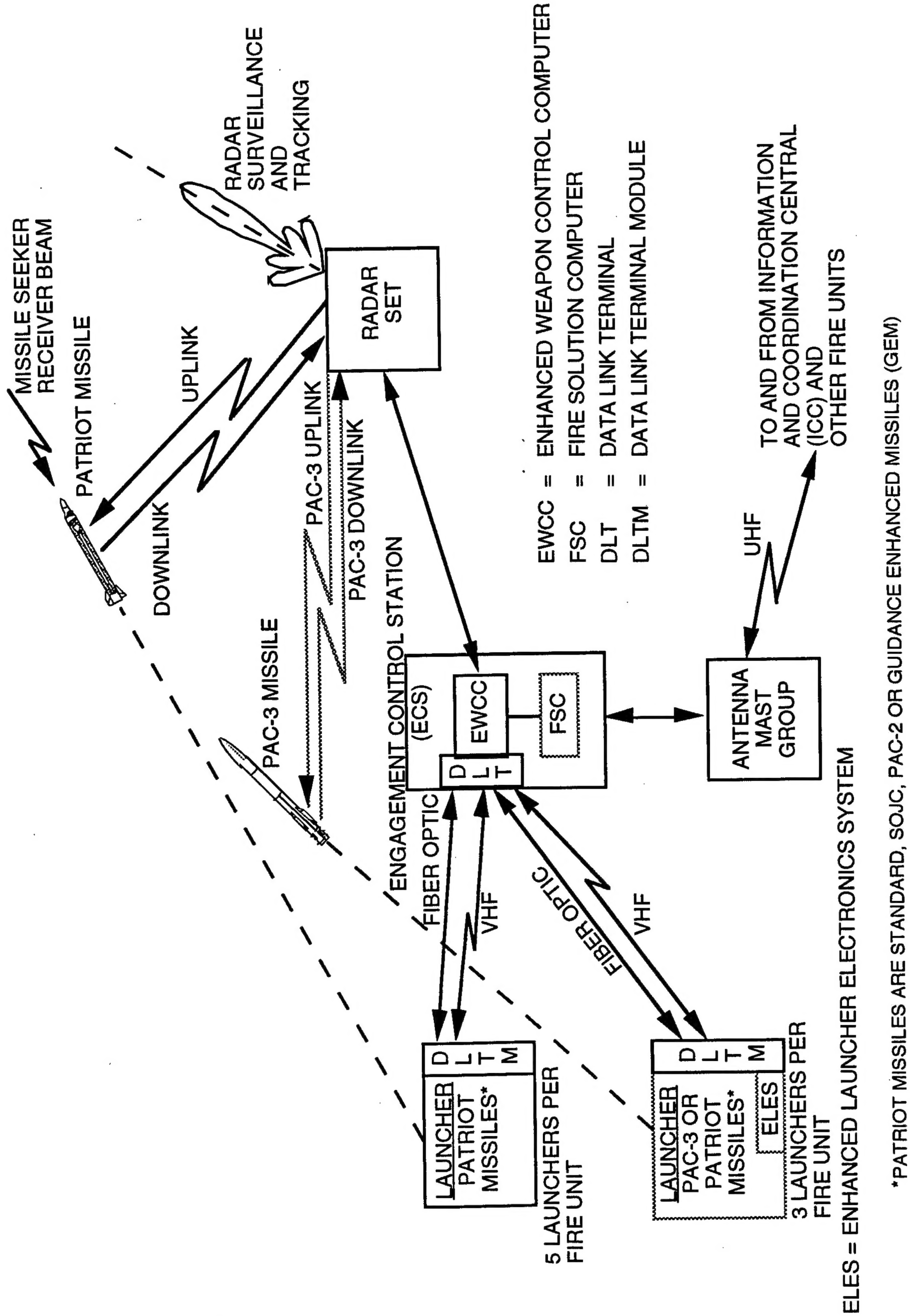

Figure 2. PAC-3 Missile Integration Block Diagram

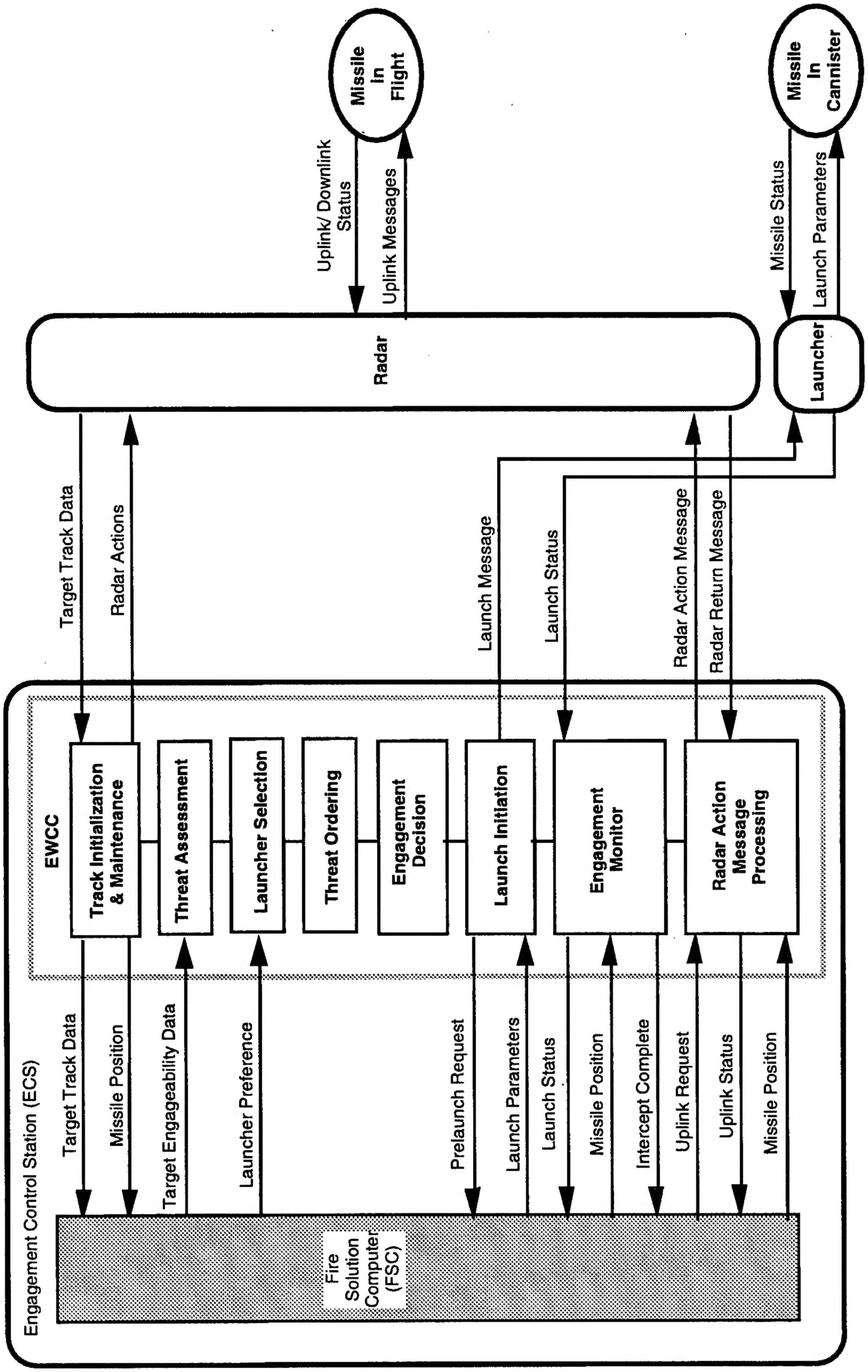

Figure 3. PAC-3 Missile Segment Integration Interfaces

Patriot Launching Station

The Patriot Launching Station (LS) is being modified to perform the launch function for the PAC-3 Missile. Similar to the other modifications of the system, the LS is being modified in a manner which maximizes user operational flexibility while maintaining the existing system performance. Specifically, the LS will also meet the following driving requirements:

1) LSs will maintain the capability to launch pre-PAC-3 missiles with a simple field reconfiguration. This provides the field commander with the flexibility to fight the war with all types of Patriot missiles; however, the PAC-3 LS is not required to operate with PAC-3 and pre-PAC-3 missiles on the same LS at the same time.
2) Carry a load of sixteen (16) PAC-3 Missiles. The pre-PAC-3 Missile load is four (4) missiles.
3) Maintain the operational requirements of the Patriot LS, including march order and emplacement time, and reload time.

Additional goals were placed on the PAC-3 LS design to minimize modification and life cycle costs. The first goal was to maintain as much of the LS mechanics and frame as possible. This was done by requiring the PAC-3 Four-Pack to mount to the LS in the same manner as a pre-PAC-3 Canister and requiring the Four Pack to maintain the same or a smaller physical outline than a pre-PAC-3 Canister. The additional weight of four Four-Packs is within the capability of the LS frame and the azimuth and elevation drive motors. In addition to reducing modification costs, these design goals minimize logistics support costs by allowing the same loading equipment, loading procedures and personnel to be used for each missile type.

The Enhanced Launcher Electronic System (ELES) provides the electronics necessary to support the launch function for PAC-3 and pre-PAC-3 missiles. The ELES receives launcher actions messages (LAMs) from the DLTM and sends launcher response messages (LRMs) to the DLTM, in the same format as the Patriot Launcher Electronics Module (LEM) does on the existing launcher. As previously mentioned, a new set of PAC-3 Missile LAMs and LRMs have now been added. The ELES mounts in the same space as the LEM on the current launcher (roadside just aft of the gooseneck and in front of the turret, see Figure 4). Since the ELES is heavier than the LEM by approximately 400 pounds, the LS structure beneath the LEM is modified with a simple steel strengthening bar.

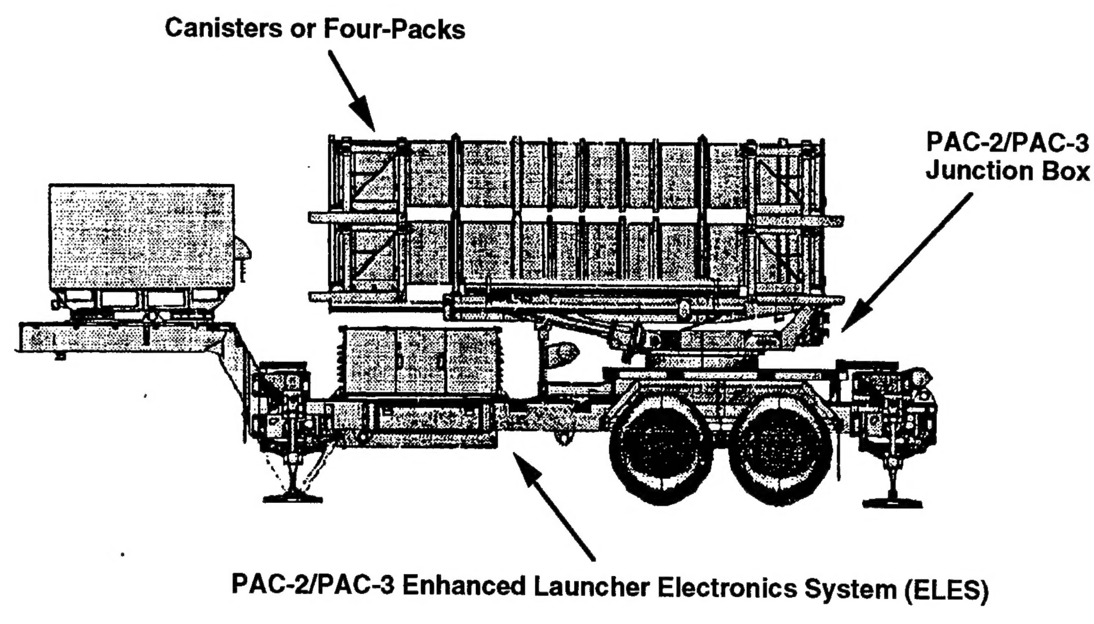

Figure 4. PAC-3 Launching Station

A junction box sits at the rear of the PAC-3 LS underneath the canisters or Four-Packs. The junction box provides the interface between the missile umbilical cables and the ELES and serves the purpose of minimizing the length of the cables that are required to be moved during reload, the most common operation on the launcher. Without the junction box, reload would require the reconnection of cables which were greater than 20 ft in length for each reload, which would then require a complex and expensive swap-out in the event of umbilical cable failure. The PAC-3 umbilicals (two required per Four-Pack) are approximately 3-6 ft in length. The junction box also allows for the continued use of the proven pre-PAC-3 Missile umbilical design.

Nine of thirteen cables between the ELES and the junction box are fixed and do not require movement during reload or reconfiguration of the LS from pre-PAC-3 missiles to PAC-3 missiles, and vice versa. Four of the cables are moved to a different ELES connector during reconfiguration only.

The umbilical cables for Pre-PAC-3 Missile Canisters are stored in place when the LS is in the PAC-3 configuration, and the PAC-3 Four-Pack umbilical cables are stored in place when the LS is in the Pre-PAC-3 Missile configuration. Some additional LS bracketing is required to do this. This design eliminates the need for additional storage space for the umbilical cables not in use and prevents loss of cables in the field.

Post Launch Communication

Once in flight, communication with the PAC-3 missile is via uplink actions transmitted by the Patriot radar. Normally all uplink actions originate with an FSC request. The missile responds to each uplink with a downlink response message. The downlinks are used by the ground system to confirm missile receipt for uplinks, to provide correction data for missile position errors, and to provide missile status data to the ground.

PAC-3 missile uplink/downlinks are supported by the Patriot Radar in much the same manner that the prior Patriot missile uplink/downlinks are supported. The approach has several system advantages. It avoids duplication of hardware by using the same control logic, transmitter, receiver, and antenna systems for all types of Patriot missiles. It also allows common management of the uplink/downlink communications for all missile types. As a result, hardware duplication is avoided and impact on the deployed Patriot logistic support system is minimized.

Some radar changes are required to support the increased data requirement of the PAC-3 uplink. The PAC-3 missile requires an uplink of 192 data bits versus the 96 data bits required for the other Patriot missile uplinks. This is accommodated by a new design in an uplink module to increase available memory. In designing the new module around current technology, this module will support uplinks of up to twice the design requirement for the same cost and development risk. The hardware design, supporting up to 384 bits of uplink data, will support uplink growth if required at a later date. More immediately, the design improves Patriot radar testability by allowing creation of more complex test vectors to test, verify, and diagnose the ground hardware that supports the uplink/downlink system. The radar retrofit is small, requiring replacement of three modules (memory card and two ROM cards containing the software to control the memory card), and some limited backplane wiring changes.

The PAC-3 missile uplink will be sent as a C-Band radar action similar to other Patriot uplinks. The uplink is requested by the FSC based on its monitoring of the target and missile trajectories. The FSC also requests uplinks for some supporting functions, including initial missile acquisition, missile alignment, missile status queries, and kill assessment. The FSC insures that each in flight missile is regularly accessed via uplink to ensure the ground system can have positive control of the missile. While the FSC can request a command destruct uplink, the Patriot EWCC will normally initiate this uplink to ensure timely friend protection in the defended airspace.

The missile responds to each uplink with one of three types of downlink responses as directed by the uplink message. Most responses will be simply a standard Patriot Barker code reply, consisting of a Barker code word (to indicate missile receipt of a valid/invalid uplink), followed by several words containing missile status parameters. Depending on the environment, the response can be a Patriot 'Super Barker' which provides additional processing gain. The third type of response contains the Barker code word, followed by an expanded set of missile status parameters which aid in the assessment of engagement performance.

Designation of Target and Handover

Lockheed Martin Vought Systems is responsible for the PAC-3 Missile acquiring the designated target from the Patriot Radar data which is sent to the Fire Solution Computer (FSC). The relative missile to target designation errors, however, are a function of parameters in the ground system and the missile. Raytheon and LMVS have constructed budgets to track the contributors to seeker pointing angle error, range error, and range rate error in all expected PAC-3 Missile intercept conditions, including ECM conditions. These parameters are then analyzed by LMVS, with Raytheon support, to determine when and if angle, range and doppler searches are required. Table 1 lists the contributors and the company responsible for characterizing and tracking them.

Fielding and Logistics

All modifications to the ECS will be accomplished via a standard Patriot Field unit sweepdown (Sweep V, currently, scheduled to begin in 1999). The modification to the RS will be either incorporated during the same field sweepdown or they can be accomplished as a part of the upgrade of radars to the full Configuration 3 capability at the Raytheon Andover manufacturing facility. Modification of LS to the PAC-3 capability can be accomplished either in

the field or at a depot. This simple modification approach will minimize cost and downtime of operational units.

All changes to the Patriot System are being incorporated directly into the mature Patriot logistics products (LSAR, Technical Manuals, provisioning documentation, etc.) For Lockheed Martin Vought System (LMVS) designed and built items, the new logistics data is generated by LMVS and integrated into the Patriot System by Raytheon.

Status of Current Program

The PAC-3 Missile Segment Integration EMD program began in October 1994 and is scheduled to be complete in July 1999 concurrent with the Configuration 3 upgrade to the Patriot System. Both the Missile Segment hardware design baseline (by LMVS) and the end item modification hardware design baseline (by Raytheon) have been established with the successful completion of the Missile Segment CDR in March 1996. Hardware requirements to populate the test bed facilities and assets have been defined and delivery began in January 1996. The Interim Interface Control Specifications produced during Dem/Val have been incorporated into both new and existing Patriot Interface Control Specifications and placed under Government configuration control. Similar to the proven Dem/Val software development/test approach, a multi-phase approach has been implemented to incrementally add the functionality required to complete the tactical software. This software will be fielded with Post Deployment Build-5 (PDB-5), the next major Patriot software build which is a part of the Configuration 3 upgrade. In addition, software functionality scheduling has been coordinated between the contractors' software builds to ensure subsequent flight test objectives are supported by the ground software. Two phases of integration testing have been successfully completed leading up to support of the first CTF flight test scheduled for March 1997. The Engagement Control Station (ECS) tactical software to be used in performing the two control test flights and the first four guided flight tests is currently in integration testing at Raytheon and will transfer to the WSMR test bed during the fall 1996 time frame.

TABLE 1 - PATRIOT SYSTEM INTERCEPTS DESIGNATED TARGET WITH PAC-3 MISSILE

	Responsibility	
Parameters	**Raytheon**	**LMVS**
Alignment/Emplacement Errors		
Radar relative to true north	X	
IMU relative to launcher		X
Launcher relative to true north	X	
IMU relative to radar after inflight alignment		X
Radar Track		
Radar target track measurement error	X	
FSC target track filter noise reduction		X
Radar missile track measurement error	X	
FSC missile track filter noise reduction		X
Missile		
Seeker relative to IMU alignment error		X
IMU inflight drift		X
Seeker acquisition range		X